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CONTENTS

	Page
Light and Vision, by Sir John Parsons, C.B.E., F.R.C.S., F.R.S. *(Fellow)*	99
I.E.S. Fellowship	109
Note on Window Calculations, by T. Smith, F.R.S.	110
Additions to List of Members	118
Proceedings at Annual General Meeting	119

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LIGHT AND VISION

By SIR JOHN PARSONS, C.B.E., F.R.C.S., F.R.S. *(Fellow)*

(Address delivered on Tuesday, May 11th, 1943.)

I wish first to express my appreciation of the honour conferred upon me by being asked to give this address—a task which in normal times is performed by eminent experts on lighting from abroad. We may hope that it will not be long before we can revert to the normal procedure. In the meantime it may be useful to review the activities of the Society during the thirty-three years of its existence—to recall its original aims and to discover how far they have been accomplished.

Introduction

As one of the founder members of the Society I am not altogether unfitted to carry out this duty. I cannot lay claim to any inspiration to set the ball rolling. I was invited by the real founder, Mr. Leon Gaster, to attend a dinner at the Criterion Restaurant on February 9, 1909, on the plea that I might be glad to meet a number of people who were interested in lighting problems. I found to my surprise that the real object of the dinner was to inaugurate this Society, and to my consternation that I was expected to make a speech. In it I naturally emphasised the importance of the physiological and pathological aspects of good and bad lighting respectively.

I should like to say a few words of appreciation of Mr. Gaster. It is entirely due to him, an engineer and physicist, that the aims of the Society were not limited to the purely physical problems involved. His breadth of vision enabled him to recognise that good lighting also involved physiological, pathological, psychological, and even aesthetic factors. The ideals which he set before the Society embraced all these aspects of the subject. Mr. Gaster was also a diplomatist. I may be treading on dangerous ground when I recall the fact that the predominant adjective in his speech was the word "impartial," for I think he had some qualms as to how gas and electric lighting experts would work in double harness. I have no doubt that it was for this reason, and not for any special qualifications which I possessed, that he wished me to be the first President. I pointed out to him that it would be much better to have a professional physicist; and that is how it came about that Professor Silvanus Thompson was elected. In his Inaugural Address at the first meeting on November 18, 1909, Professor Thompson showed remarkable foresight in visualising the future activities of the Society, a substantial part being devoted to the effects of light on the eye and to the need for research in this field.

It was deplorable that at that time there was little guidance in lighting matters from ophthalmologists and physiologists, but it must be remembered that information on the physical side was also vague. Although engineers were becoming accustomed to foot-candles the few instruments for measuring illumination were primitive and cumbersome. There were as yet few records of the illumination actually provided in different classes of buildings, though this deficiency the Society speedily proceeded to rectify. In this respect the work of Dr. Walsh and his colleagues for the Factory Lighting Committee, of which Mr. Gaster and I were members, is worthy of special mention. At that time, too, the conception of brightness in terms of candles per square inch was little understood, and there were no quick and convenient means of measuring

the brightness of sources—a need which has not yet been completely satisfied.

In those days, as Sir Francis Goodenough has said ("Illuminating Engineer," xxv., 276, 1922), "Technicians were somewhat apt to devote themselves to the perfecting of their tools rather than the objects they served. For many years the chief task had been that of producing light economically and abundantly." One may compare this with the printers, whose object seemed to be to produce a beautiful page, with no regard for legibility. Since then there has been a marvellous advance in the efficiency of illuminants, so that undue stress has been laid upon physical intensity. None the less in the first paper contributed to the Society on Glare ("Illuminating Engineer," iii., 99, 1910) I drew attention to the dangers of excessive light and the importance of the distribution of light in the field of vision.

Further, as Dr. Wright has reminded me, the average illuminating engineer is scared stiff of anything at all academic about the eye or the visual response; just as, in my own experience, the average medical student is scared stiff of mathematics and analytical optics. Being confronted with the chaos of metre-candles, foot-candles, equivalent foot-candles, lamberts, lumens, and photons, not to mention daylight factors and brills, may account for the apathy of ophthalmologists.

The Response of the Eye to Light

These opposed limitations in mental outlook are responsible for many of the errors and shortcomings of both physicists and physiologists, and for the lack of liaison between them. As I have often pointed out physicists tacitly ignore the physiological basis of all their measurements, hiding their heads under the convenient term "errors of experiment," and resorting to statistical methods to condone their ignorance. On the other hand there are many reasons into which I cannot enter now which militate against physiologists devoting themselves to research on the special senses; and psychologists who ought to make these subjects their own prerogative, are nearly without exception ill equipped for the purpose. Nearly all the experiments which have been made by psychologists and many by physiologists are almost useless owing to the absence of accurate quantitative data. The experiments of von Kries and his pupils on colour vision and those by Lythgoe on peripheral vision, etc., are noteworthy exceptions.

The problems with which this Society is concerned are pre-eminently such as cannot be segregated into purely physical and physiological compartments. The physicist has been forced to open his eyes to physiological facts. An early example is the "deviations from Newton's law of colour mixtures," as König called them, which are due to the difference of scotopic from photopic vision. On the other hand, one has only to recall the names of Newton, Thomas Young, Clerk Maxwell, Helmholtz, König, Abney, and many others down to the present day to realise that we owe most of our knowledge to physicists.

The Illuminating Engineering Society was founded for a definitely utilitarian purpose—that of promoting "good lighting." Good lighting is sufficiently well defined in the Factory Lighting Committee's report as "adequate and suitable" for the given performance. One is almost startled to find that the problem is primarily and fundamentally physiological, for adequacy and suitability depend upon the performer's capacity. Ophthalmologists knew that prolonged near work under low illumination and unsuitable conditions led to

fatigue, "eyestrain," headaches, and bad health. Industrial fatigue is difficult to measure, though much valuable work was done by the Industrial Fatigue Board of the Medical Research Council, using output as the criterion. The retina appears to be insusceptible to fatigue in ordinary conditions, and eyestrain is chiefly due to fatigue of the extraocular muscles; hence the importance of measuring convergence capacity and latent squints. Even more potent in causing eyestrain are uncorrected errors of refraction. It is only comparatively lately that examination of the eyesight of school children and the correction of their refractive errors have become compulsory, largely due to the pioneer work of Dr. Kerr and Mr. Bishop Harman for the London County Council. May we not hope that the sight of factory workers will be similarly catered for? A striking example of the value of the application of knowledge of this kind is the success of Mr. Weston's efforts to ameliorate the strain of very fine work by the use of suitable convex glasses combined with prisms.

Illumination and Visual Acuity

The rôle of illumination was little understood, and indeed still remains an only partially solved problem. In spite of the far worse conditions which obtained then and the neglect of the workers' eyesight, the first report of the Departmental Committee on Lighting in Factories and Workshops (1915) records that an inquiry addressed to about 300 oculists failed to produce any evidence of the prejudicial effect of bad lighting. I do not lay much stress on this fact, since I have a profound distrust in the value of questionnaires—so beloved by our American confrères.

Since good visual acuity is the *sine quâ non* of clear vision the effects of the quantity and quality of the illumination early attracted attention. Visual acuity is measured scientifically by the minmum visual angle subtended at the nodal point of the eye by two point sources necessary for resolution. In ophthalmic practice it is measured by the recognition of letters drawn to known scales of visual angle, e.g., Snellen's Types. So far as intensity is concerned we know now that the acuteness of vision becomes progressively better up to, and even beyond, 1,200 ft.c. Unfortunately, as Lythgoe has pointed out (Trans. I.E.S., i., 4, 1936), it was not sufficiently recognised in the early days that visual acuity is proportional to the logarithm of the illumination; so that on the linear scales then prevalent it appeared that there was little improvement above 3 or 4 ft.c. It is noteworthy that until the Council of British Ophthalmologists took the matter up in 1919 there was no standard fixed for the illumination of Test Types, and even so it was fixed at too low a level, which had to be increased in a subsequent report (1935).

Even scientifically disposed opthalmologists are liable, like other scientists, to simplify their problems unduly, and consequently to attach undue importance to isolated details. Thus, little attention was paid in the above determinations to the surrounding illumination. It has since been found that this has a very marked effect. To get the best result the surrounding illumination should be only slightly less than that of the test object, book, or work. If it is much less visual acuity falls off after a maximum at about 40 e.f.c. illumination of the test object, and if it is quite dark the maximum is reached at less than 20 e.f.c.

The Society deserves to be congratulated upon the issue of the I.E.S. Code of Illuminations adequate and desirable for different classes of work. It is largely founded upon

empirical data, and much research yet remains to be done; but that it filled a long felt need is shown by the hearty reception it has had.

Taking together the now justified predilection for higher illumination for reading and work, and the economic availability of greatly increased artificial illumination it is not surprising that people demand these higher illuminations, especially when we find that if the general illumination exceeds that of the test object visual acuity will be seriously diminished. Whether the satisfaction of this desire is being carried to extremes with deleterious results is a matter for future investigation; but the suggestion that the demand for high illumination is due to general deterioration of sight in the population is entirely unsupported by any valid evidence.

The Influence of Background

The effect of the surrounding illumination on visual acuity is one of the many characteristics of the eye as an optical instrument of precision which are so exasperating to the physicist. The retina is a part of the brain, and it is no surprise to the physiologist that there is interaction between the different parts. Much light has been thrown in recent years on this subject by the investigation of the electrical responses to stimuli by Adrian and Matthews, Hartline, Granit and others, and by the researches of Lythgoe and Tansley. It has long been known in the manifestations of simultaneous contrast. In its most blatant form excessive contrast plays a preponderating part in glare, as was indeed fully recognised in the earliest days of the Society. It was to the discussion on Glare, initiated by my paper at the first meeting that Prof. L. Weber of Kiel contributed recommendations which were substantially adopted by the Factory Lighting Committee and have even now been little modified. He advocated (1) a limit to brightness (about that of a candle flame) and (2) the location of sources outside the 30 deg. angle at the eye. But he also approached near to the root of the matter in suggesting that (3) the ratio of the brightness of the source to that of the surroundings should not exceed 100 to 1—a value deduced from daylight conditions. He had also one other special rule (4) that the area of the source of light should not subtend an angle at the eye of more than 5 deg., a condition that seems, taken in conjunction with (1), to imply a leaning towards volume of light rather than brightness as the condition determining glare.

Tests of Glare

The earlier researches aimed at a satisfactory explanation of glare by Cobb and others were disappointing, and we owe it to Dr. Stiles that it has been put upon a more satisfactory basis, though I am sure he would be the first to admit that we have only touched the fringe of the subject. Recognising that glare is largely due to scattered light, i.e., light in the wrong place, he conceived the brilliant idea of translating its effects into those produced by flooding the whole area of the retina with uniformly distributed light; thereby enabling the results to be expressed in comparable quantitative terms.

We have at present no means of detecting glare directly in the physiological sense. We have therefore to fall back on indirect and empirical methods of controlling the circumstances which, it is conjectured, will give rise to glare; for example, by limiting the brightness of sources, or specifying for them positions outside the immediate range of vision. Possibly some simplification might be effected by some general rule specifying the desirable contrast or brightness ratio between object and sur-

roundings, which would not only act as a safeguard against glare, but also ensure conditions favourable to the powers of perception of the eye. In this connection one must not forget glare due to specular reflection from polished material; nor the inconvenience and occasional danger of harsh shadows. The precise definition of shadow offers as many difficulties as the assessment of glare.

Colour of Light

With regard to the quality of light our eyes are not only capable of adaptation to the enormous range from 0.00001 to 10,000 ft.c., but also to considerabale variations of spectral constitution. Phylogenetically eyes have obviously been adapted—in the evolutionary sense of the word—to sunlight, but there is no evidence that artificial sources of so-called "white light," composed of practically continuous spectra, *per se* cause any harmful effects. These are generally due much more to the distribution of the light than to either quantity or quality. It is true that they nearly all, including the sun, emit ultra-violet radiation, but the atmosphere usually acts as an efficient filter in the case of the sun, and artificial sources are enclosed in glass which is equally efficient. The deleterious effects of ultra-violet light in everyday life have been grossly exaggerated. Similarly, the craze for "daylight" lamps, apart from special colour-matching processes, etc., is quite unwarranted on physiological grounds, though there are evident advantages in the latest fluorescent lamp, notably its high efficiency, low brightness, and resemblance to daylight, and the fact that it mixes well with natural light.

The effects of monochromatic light and of sources like mercury vapour lamps which emit discontinuous spectra, and of those with intermittent emission, especially when the cycles per second are few, are more debatable.

The phenomenal advance in the development of discharge lamps using fluorescent substances—an advance due largely to the G.E.C. Research Laboratory under the aegis of Mr. C. C. Paterson, F.R.S.—emphasises the importance of colour vision and its defects. The work of Guild and others on Colorimetry resulted in 1931 in the standardisation of colour mixture curves by the International Commission of Illumination—a fitting sequel to the standardisation of the equal energy luminosity curve in 1924 by the same body. Together they form perhaps the most noteworthy advance in photometry of recent date. Neither has the theoretical side been neglected. Dr. W. D. Wright's reinvestigation of the so-called sensation curves by more refined methods has corrected some discrepancies in the work of König and Abney; and by using the method of binocular matching, in which adaptation effects induced in one eye are measured by comparing vision in that eye with vision in the constantly dark-adapted other eye, he and others, e.g., Schouten and Ornstein, Pitt, and Craik, have elicited new facts of theoretical and practical value.

Considering the great prevalence of colour blindness in different degrees —at least 5 per cent. of the male population are badly colour-blind—it is remarkable how little this disability seems to affect everyday life. The secretary informs me that he knows of no case of colour-blindness among the 1,000 members of this Society. Yet many of these are constantly engaged in delicate photometric observations. In most such tests difference in hue of the test objects is reduced to a minimum, so that the estimate is one of equality of brightness in two white lights. There is some evidence that pure brightness

discrimination is actually better in the colour-blind than in the normal—a fact which has been adduced as a factor in the excellence of the etchings of Méryon. I suppose that in the grosser forms of heterochromatic photometry the results are always controlled by the flicker method. We may hope that Dr. Wright's researches will throw further light on the luminosity curves of the colour-blind. Even in colour matching, however, such colour-blinds as conform with the Trichromatic Theory would be expected to accept the normal matches. In fact, they do so, but, unfortunately, as Prof. William Watson pointed out, they will also accept considerable deviations from the normal match.

Vision at Low Illuminations

Until the outbreak of the war and the initiation of the "black-out" illuminating engineers paid little attention to the peculiarities of vision under very low illuminations. Probably their first experience of these was due to anomalies in photometric observations caused by the Purkinje phenomenon. Previous to the "black-out" town dwellers had little experience of complete dark adaptation, and it is therefore not surprising that they should be found to be psychologically relatively night-blind compared with country dwellers. Attention was first seriously devoted to the subject when exhaustive researches were made to improve street lighting and put it on a satisfactory scientific basis. The Factory Lighting Committee were faced with the problem of setting up standards for the illumination of passages in factories, non-working areas, dockyards, and so on. These were fixed as follows: (a) over interior parts of a factory other than working areas, 0.1 ft.c. (1915), subsequently increased to 0.1 ft.c. to 0.5 ft.c. (1938); (b) over open yards, etc., not less than 0.05 ft.c., subsequently increased to from 0.05 ft.c. to 0.1 ft.c. In the present circumstances the conditions of vision under moonlight and starlight illumination are literally of vital importance to airmen and other combatants.

None of the standards hitherto set is based on really satisfactory scientific evidence, partly on account of the ignorance of physicists and illuminating engineers of such facts of the physiology of scotopic vision as are known, but much more because of the ignorance of the physiologists themselves. A vast amount of very valuable work has been done on night vision for the Services, especially the R.A.F., and, while it has been of immense practical utility, it has but served to reveal the extreme complexity of the subject.

Dark adaptation is characterised by a phenomenal increase (from about 0.00001 ft.c. to 10,000 ft.c.) in the sensitivity of the retina, which rises rapidly during the first ten or fifteen minutes and reaches a maximum in about three quarters of an hour. This rise in sensitivity shows some variation in the normal population, but there are pathological cases in which it is delayed and defective and may be very bad.

When a spectrum of low intensity is viewed by the dark adapted eye it appears as a colourless band, having a luminosity curve which is of the same general type as the photopic luminosity curve, but having its maximum at about 500 $\mu\mu$ instead of 550 $\mu\mu$. This shift of the luminosity curve accounts for the Purkinje phenomenon, in which the apparent brightness of the short wave-lengths is much enhanced compared with the longer wave-lengths.

Visual acuity, even under photopic conditions, falls off very rapidly as

the fixation point is shifted from the centre, i.e., direct vision to the periphery.

In order to show how very complicated scotopic vision is, it is necessary to remind you of the anatomy and physiology of the retina. The retina is an outgrowth of the brain and is a membrane which has properties similar to but even more complicated than a photographic film. The receptive cells are called rods and cones, and these are connected with higher centres in the brain by an intricate system of cells and nerve fibres. The area of most distinct vision is near the posterior pole of the eye. It consists of a central depression, the fovea, surrounded by an oval pigmented area, the macula lutea or yellow spot. Nearly the whole of this area almost invariably contains only cones. The retina surrounding it contains both rods and cones, the former increasing, the latter diminishing in number rapidly towards the periphery. The fovea, which is the site of highest discrimination or visual acuity, subtends a visual angle at the nodal point of the eye of 60 min. to 70 min.; the macula is oval, with the long axis horizontal, subtending a visual angle of 4 deg. from above down and 12 deg. across. The deeper layers of the retina not only conduct impulses directly to the brain, but have intercommunications which permit of modifications in the responses of adjacent areas.

It is certain that the rods contain a photochemical substance which subserves the transformation of the physical stimulus into a nervous impulse. This substance, rhodopsin or visual purple, appears to be absent from the cones, where it is almost certainly replaced by a similar photochemical substance or substances. Visual purple is bleached by light, and its absorption curve is identical with the scotopic luminosity curve, so that it is practically certain that it is the physiological basis of vision under very low illuminations. Dark adaptation is due to the accumulation of visual purple, and since rods are absent in the greater part of the macula, it might be expected that this area would be night-blind. That this is indeed the case was discovered long ago by astronomers, who found that a star of very low magnitude could be seen only by looking at it eccentrically, so that the image fell upon a parafoveal spot. The macula is not, however, wholly incapable of dark adaptation: such as it possesses is indeed slight, but rapid in development.

The researches of Lythgoe and Goodeve, and of Wald have thrown much light on the constitution and properties of visual purple. It has long been known that in certain cases of malnutrition, e.g., xerophthalmia, night blindness is a cardinal symptom. It is now known that the presence of vitamin A is essential to the regeneration of rhodopsin. As a result a vast amount of work has been done in the hope of improving night vision by administering large doses of vitamin A. The evidence seems to prove that this has little or no effect on normal subjects, but that if the defect is due to malnutrition the effects are striking.

König showed many years ago that if the effects of illumination on brightness discrimination are plotted on a logarithmic scale two straight lines of different slope result, the kink occurring at about 0.25 metre-candles (0.023 ft.c.). This has been confirmed by flicker photometry: and the same curves are obtained with the effects of illumination on visual acuity. There can be little doubt that, in accordance with the Duplicity Theory, the scotopic part of the curve is due to rod vision and the photopic to cone (± rod) vision.

The transition from day vision to night vision therefore occurs when the illumination decreases to less than that provided by the full moon, about 0.023 ft.c., night vision being fully

established at illuminations of less than 0.01 ft.c. Above the upper limit photopic, foveal, cone vision will be in the ascendant; fixation will be good, and visual acuity good. Below the lower limit scotopic, rod vision will be used; fixation will be bad, parafoveal, and fluctuating owing to rapid fatigue of the rods, and visual acuity will be bad. At the intermediate levels fixation will be fluctuating, and it is likely that vision will be worse than might be expected owing to rivalry between the two systems.

But there are other factors which make the complexity of scotopic vision much greater. The chief are the size of the area stimulated and the contrast or brightness discrimination at these low levels of illumination. For visual angles up to about 40 min. to 50 min. Ricco's law holds good for central vision; i.e., at the threshold the product of the area into the light intensity is constant, or, the product of the minimum visual angle and the light intensity is constant. The threshold luminous flux is about 0.2×10^{-12} lumen for extra-foveal. and 8×10^{-12} lumen for foveal vision. For larger areas the total luminous flux is no longer alone responsible for the threshold. According to Piper the product of the threshold intensity into the square root of the area is constant, but this is only valid for white light and objects subtending a visual angle up to 10° (Henius, Fujita). Similar laws hold good for the detection of the orientation of Landoldt's broken ring (C), or an E; but this only shows that these are really tests of brightness discrimination, and are quite unsatisfactory tests of true visual acuity or form vision—at any rate at low intensities of illumination.

Brightness discrimination depends upon the area even at normal levels of illumination. With a photometric field of 5° the eye has to work with regions of the retina which differ in sensitivity, and more consistent results are obtained when the visual angle is reduced to 2½°. At 1° vision is foveal and purely photopic, and there is no kink in the logarithmic curve. The transition occurs at about 0.03 e.f.c., the order of brightness provided by the full moon, and is responsible for the low values of $\triangle$ B/B which are obtained with large fields at intensities far below those at which discriminating capacity vanishes with smaller areas. It is important to remember that $\triangle$ B/B expresses only relative brightness difference in terms of stimulus values, and is only valid as an expression of physiological apparent brightness difference or true contrast over the limited range in which the Weber-Fechner law holds good. The difficult problem of brightness and contrast is discussed in an excellent paper by Hopkinson, Stevens, and Waldram (Trans. I.E.S., vi, 37, 1941). The discordant results obtained by different observers are largely due not only to the differences of size and shape of the test areas, but also to the size of the illuminated surrounds. When the test field is exposed for only a short period of time a higher percentage of contrast is needed to produce a just noticeable difference.

Hopkinson, Stevens, and Waldram point out that when the adaptation level is reduced the instantaneous visual range of appreciable brightnesses is not symetrically disposed about the adaptation level, as is approximately the case at the normal levels. "The eye can then distinguish brightnesses greater than that to which it is adapted, but not much to lower brightnesses"—a fact of great significance in street lighting and aeroplane spotting. It is also of considerable importance in the measurement of low values of illumination and brightness, a subject dealt with by Dr. Walsh (Trans.I.E.S., vi., 117, 1941). There is little reference

to physiological conditions in this paper, except that in speaking of the Purkinje phenomenon the author says that "one can easily live in a fool's paradise." It seems to me that, in the present state of knowledge, the same remark applies to making measurements in which "the range introduced is 0.0005 to 0.3 ft.c., and the corresponding limit of error laid down is 20 per cent. + 0.0001 ft.c." (Specification for Portable Photometers (Visual Type), 230. 1935). Fortunately, Dr. Walsh realises that "the necessity for measuring apparent brightness, rather than brightness based on a physical scale, is perhaps the most striking of these new developments."

The lowest level at which consistent data as to the influence of contrast on visual acuity have been obtained is 1 ft.c., which is much greater than that prevailing at night; even for this illumination for less than 10 per cent. contrast large increases of size have to be made. Riccò's and Piper's results indicate the decreased importance of contrast at low intensities. Their results also show that in using field-glasses at night, with visual angles between 10′ and 2°, the size of the exit pupil, and therefore the amount of light gathered, is more important than the coefficient of magnification.

Vision and Illuminating Engineering

I should like now to make a brief reference to some researches in which members of the Society have been concerned, since they illustrate the close connection between vision and illuminating engineering.

One of the first undertaken was the pioneering work done by the committees dealing with the lighting of schools and libraries, which reported in 1913. It afforded one of the first instances of co-operation with other bodies. It dealt with both natural and artificial lighting, and it initiated a great deal of original work, especially in connection with photometry and daylight measurements. These workers were essentially pioneers. There was little or no information available in regard to the illumination actually prevailing in schools and libraries; there were no data at all based upon study of the requirements of the eye, and photometric apparatus was then in its infancy. The Committee had to ascertain by experiments on themselves what lighting people would put up with and what was desirable, and to discover by personal visits what was practicable.

The Departmental Committee on Lighting of Factories and Workshops, formed about the same time, had to contend with similar difficulties. There was no evidence to establish positive injury to workers under feeble illumination. The Committee had to be guided primarily by the opinions they elicited, and to check their recommendations by the laborious means of "frequency occurrence" curves showing the actual levels of illumination in factories at that time. Sir Duncan Wilson and I are, I think, the only members of the first Committee serving on the present one. We have seen the gradual evolution of legislation in factory lighting, the successive rises in the standards recommended, and the recognition of the "I.E.S. Code" as an indication of modern requirements. Yet, even now, the task is far from completed, and the most recent reports of the Committee envisage much further research for the future. It is singular that this effort, initiated just before the outbreak of the last war, has come to fruition in the present one.

The introduction of legislation on factory lighting may well furnish a precedent in connection with other fields of lighting after the war. Sir Duncan Wilson urged legislation on factory lighting early in his career as Chief Inspector of Factories, and this has now been granted. That

similar legislation, supplemented by orders specifying details and subject to adjustment from time to time, should be extended to normal street lighting, schools, etc., has recently been wisely advocated in "Light and Lighting" (Dec., 1942).

One other research conducted by the Society may be singled out for reference, the enquiry into Eyestrain in Cinemas for the London County Council, which formed the subject of a report issued in 1920. The Committee responsible for that enquiry furnished an excellent instance of the fitness of the Society to gather experts drawn from different professions under its wing. As Chairman of the Committee I have a keen recollection of the good team work and enthusiasm of these experts. In some respects this enquiry may seem remote from ordinary illuminating engineering, but it showed the competence of the Society to launch out into fields a little off the beaten track. It may be regarded as supplementary to another investigation into the lighting of cinemas, likewise undertaken by the Society about twenty years later. These researches had the great merit of resulting in a grant by the L.C.C. of fifty guineas to the Society's funds!

I do not wish this address to be regarded as an attempt to give an "adequate and suitable" review of the work of the Society since its inception. I have selected topics with which I am most familiar: but I fully realise that the bulk of the work relates to matters with which I am quite unqualified to deal. With these, however, you are all already thoroughly conversant. That they are being satisfactorily catered for is evidenced by the remarkable success of the Society. Such success could not have been brought about merely by the foresight and energy of Mr. Gaster. I think an even greater share of praise and gratitude is due to one whose knowledge, indomitable perseverance, tact, and modesty is known to you all. I refer, of course, to Mr. J. S. Dow.

The I.E.S. Code

In spite of the urgency of the immediate problems of this wartime period we must not neglect to make plans for the future. The President has twice given us a lead: first by his talk on lighting in relation to post-war reconstruction two years ago, and again in his recent Presidential address, when he emphasised the importance of making known such knowledge as we have already acquired. I should like to endorse this plea, and to supplement it by an encouragement to pursue the knowledge not yet acquired. To quote from "Law — and Order" ("Light and Lighting," Dec., 1942): "How comes it that the I.E.S. Code has become virtually law in wartime? Because, when war broke out, it was there ready. Therefore, get to work now. Make certain that when peace comes all the data, all the reports, all the specifications we need are ready too."

The work of the Factory Lighting Committee has drawn attention to several gaps in our present knowledge, which constitute a challenge to the Society: such as—evidence of the shortcomings and prejudicial effects of inadequate illumination; the scientific determination of the order of illumination necessary for a particular task; the determination whether an installation is marred by "glare" or other defects which handicap the workers; the scientific definition of those vaguely expressed factors involved in "quality of lighting," in which contrast and background are so intimately involved. Though these problems have been stressed chiefly in relation to industry they clearly have a bearing on all forms of lighting problems.

An encouraging start has already

been made. The Society has been fortunate in possessing several members who have made brilliant contributions to this field of knowledge. I may recall, for example, Mr. A. W. Beuttell's paper outlining the basis of a scientifically determined code of lighting ("Illum. Engineer," Jan., 1934), the skilful and patient work done by Mr. H. C. Weston on certain of the factors indicated by Mr. Beuttell, such as the effect of size of object and contrast on the desirable illumination; and the extremely valuable work of Dr. R. J. Lythgoe, whose untimely death leaves a gap well-nigh impossible to fill.

Mr. H. C. Weston has this year contributed a paper of outstanding importance, suggesting a fundamental basis for the values of illumination presented in the I.E.S. Code, which bids fair to enhance the value of the code by giving it a scientific background without greatly disturbing the present set of values, which have become standard. There is still to be added to this code particulars of essential requirements in regard to *quality* of lighting, more especially the maintenance of desirable contrast and the elimination of glare.

The main functions of the Society have been well catered for in the past, and the formation of provincial Centres and Groups has thoroughly justified itself by arousing local interests and attracting attention to the needs of local industries. But "these things ought ye to have done, and not to leave the other undone," and the amenities of everyday life might be considerably improved if more detailed attention were paid to such problems as the distribution, quality, and aesthetic effects of domestic lighting. The experience of the Factory Lighting Committee has shown that problems of this kind are not so simple as might be thought. Many of the inconveniences which we grumble at but put up with—rooms in which it is almost impossible to read or sew with comfort, bedrooms with half a dozen mirrors in none of which it is possible to see to part one's hair or shave—might be eliminated or ameliorated if architects would take the trouble to learn from illuminating engineers and insist upon builders carrying out their instructions, such as putting in the lighting points where they ought to go, and not where the builder finds it most convenient for himself. The definition of the edges of steps and stairs and their lighting still seems to me to be unsatisfactory. Perhaps these and other similar problems might be referred to an Architectural Committee: but what I think is much more necessary is the establishment of a standing Physiological Committee.

I.E.S. Fellowship

The following applications for Fellowship have been accepted by the Council:—

Ames, J. E.
Davey, W. J. G.
Illingworth, T. E.
Kidd, A. G.
Lay, Stuart D.
Purdie, H. Ayres.
Winch, G. T.

I.E.S. Post-War Activities

The President desires to thank all members who have responded to his circular letter on the above subject. These replies are being closely studied by him and by the General Purposes Committee. In the meantime only formal acknowledgement of letters can be made.

The Illuminating Engineering Society is not, as a body, responsible for the opinions expressed by individual authors or speakers.

With a view to avoiding possible confusion with other publications, reference to these Transactions should be in the form:—"Trans. Illum. Eng. Soc. (London)."

NOTE ON WINDOW CALCULATIONS

By T. SMITH, F.R.S. (National Physical Laboratory)

(Communicated)

Abstract

Simple equations are obtained for ascertaining the window area necessary to secure a given penetration of daylight into a room and for the determination of daylight contours. Evidence is given to show that the results to which these equations lead are of good accuracy.

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1. Speaking on technical problems of interest to his own and some other professions, an architect recently stated that he knew no convenient direct method of finding the window area needed to give a definite daylight factor at a given position in a room. This note is offered as a partial response to the invitation implicit in this statement.

I assume that a broad division may be made of these lighting problems into two groups. In the simpler and perhaps larger group it will be known from the outset that the illumination will be satisfactory if an assigned amount of daylight penetrates to a certain depth in the room. In these cases, both those where there is a clear view of the sky and those where obstructions are present, the information desired can be calculated readily from a simple formula; it could, of course, be made immediately available by means of numerical tables. In the other group will occur those cases where the conditions are less simple, such as those that arise from the presence of windows in more than one wall and those in which it is necessary to consider the areas over which given standards of daylight illumination are obtained. To deal with these a simple formula for the computation of daylight contours has been constructed and has been found to give very accurate results. The treatment of problems belonging to this group can probably best be based on a series of standard daylight contours corresponding to conditions that occur frequently in practice.

As the application of the formulae is of wider interest than their theoretical derivation, I give first the relation to be used with illustrative calculations, and secondly an indication of the accuracy obtained. The mathematical theory follows at the end of the note in a form which, though brief, will, I hope, be full enough for those who wish to consider it.

2. The relation proposed for the calculation of window areas is

$$A = \frac{\pi f R^3}{H} \quad \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

where A is the window area, H the height of its centre above the working plane, and f the daylight factor to be obtained at a point of the working plane at a distance R from the window head. This point is supposed to be on the line in the working plane normal to the plane of the window which meets the centre line of the window. Fig. 1 illustrates these measurements.

The factor π is that required for an unglazed window. If the loss of light

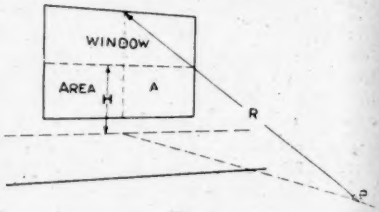

Fig. 1.

caused by reflexion and absorption in the glass is to be taken into account, and also an allowance made for an average deposit of dirt on the window, the area would have to be increased by about 15 per cent. In place of π a coefficient of, say, 3.7 would then be suitable.

3. When the sky is not obstructed and the window extends down approximately to the working plane H may be replaced by half the height of the window head. This substitution is advantageous as the height of the window head is a key measurement in building design. To take a numerical example, let us find the window area required to give a daylight factor of

1 per cent. at a point 10 ft. from the window plane, when the height of the window head is 5 ft. From a drawing or otherwise this gives R = 11.18 ft., and, taking glazing losses into account, we have

$$A = 3.7 \times \frac{1}{100} \times (11.18)^3/2.5 = 20.68 \text{ sq. ft.}$$

The requirement would be substantially met by a window 4 ft. wide and 5 ft. high.

4. The same formula is suggested for use when the view of the sky is partly obstructed, as represented in Fig. 2. In these circumstances we

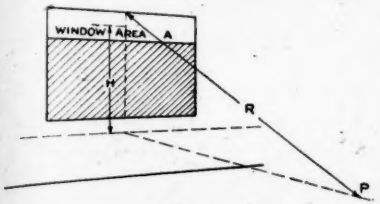

Fig. 2.

are to understand by A the area of window through which the sky is visible from the working point, and by H the height of the centre of this part of the window. Taking the ordinary case when the obstruction is due to a row of buildings running parallel to the window plane, from the height and position of these buildings we find the height of the line in the window plane below which the view of the sky is obscured. H is the mean of this height and that of the window head. Thus if the window head is 5 ft. above the working plane, and for a point 10 ft. from the window the sky is obstructed below the 4 ft. level, the value of H is 4.5 ft. or 4 ft. 6 in. If the daylight factor at this point is to be 0.2 per cent. the window area required is

$$A = 3.7 \times \frac{0.2}{100} \times (11.18)^3/4.5 = 2.3 \text{ sq. ft.}$$

As the depth of this area is 1 ft., the window must be 2.3 ft. wide. If it is to extend down to 6 in. above the working plane its dimensions would thus be 2 ft. 4 in. wide and 4 ft. 6 in. high.

5. Formula (1) may be used in calculations when part of the sky is obscured by a balcony projecting above the window. In this case, by the head of the window we are to understand the highest level through which the sky is visible from the working point.

6. The formula (1) suggested for these calculations depends largely for its convenience on the fact that window shapes, as distinct from window areas, do not call for consideration. In reality windows of the same area but of different shapes will give different penetrations: fortunately, the effect of varying the window proportions is somewhat small. They can be taken into account if desired by changing the point in the window from which the distance R is measured. Whatever choice is made the error of the formula as the window shape is altered will vary in substantially the same way. This is apparent from Figs. 3 to 6, which show the percentage errors in the computed daylight factors made by a selection of formulae of this class for unglazed windows 5 ft. high and of widths up to 20 ft. They are computed for two points respectively, 12 ft. and 24 ft. from the window plane.

The broken curves of Fig. 3 refer to the formula of this series which is correct for windows of vanishingly small area. There is no need to discuss this purely theoretical case in detail. The other curves shown relate to selections having some property that may be of practical value. In those marked B the distance R is measured from the centre of the effective window area, the point to which H also refers. Since this is the only point of the window of which the formula takes account, window areas computed by this formula could be recorded in a single-entry table.

The curves marked C are based on a choice which makes systematic errors substantially independent of sky obstruction. This is at once apparent on comparing Fig. 5 with Figs. 4 and 6.

The curves marked D show the errors which follow from the use of the formula proposed in this note. By measuring R from the window head the errors in the daylight factor become negative rather than positive, as with the other formulae mentioned. In consequence the tendency is slightly to overestimate the window area required to secure a given daylight factor for windows of all normal

shapes, and I consider that this is the bias that a satisfactory formula should show. It may also be regarded as a merit that values are closely related to ceiling height. In computed tables the horizontal distance of the working point from the window plane would be shown rather than the distance R used in constructing the tables.

7. It remains to consider problems of the second group which involve knowledge of daylight contours.

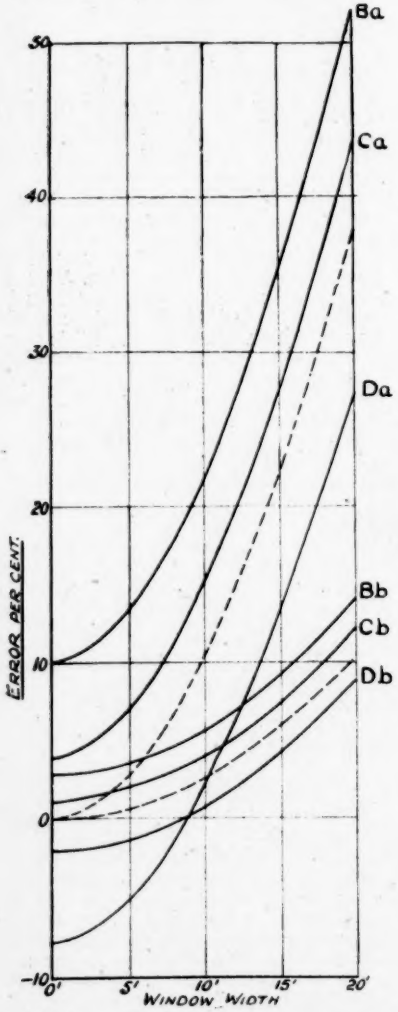

Fig. 3. Errors in daylight factor formulae for a window 5′ high for points (a) 12′ and (b) 24′ from plane of window.

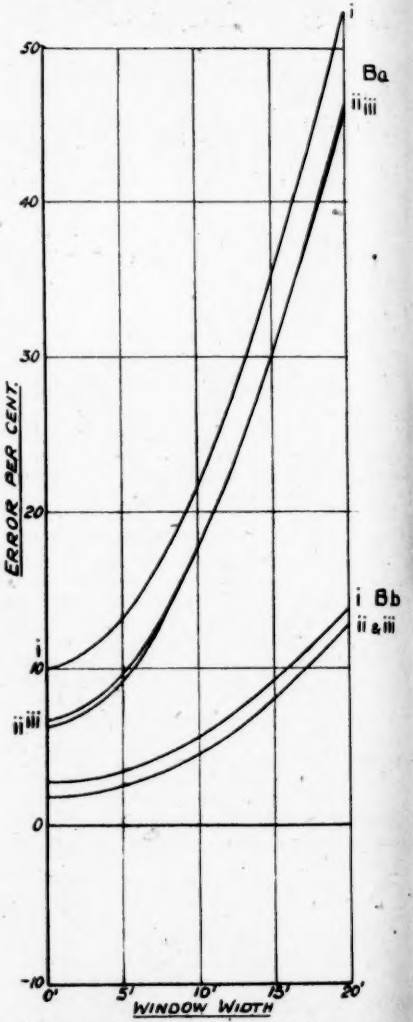

Fig. 4. Change in errors with B formula due to obstruction—i, no obstruction, ii, lower half, and iii, bottom three-quarters obstructed.

The formula proposed for the calculation of contours contains three constants—W the width of the window, and k_1 and k defined by

$$k_1 = h_1^2 + \frac{1}{12}W^2,\ k_2 = h_2^2 + \frac{1}{12}W^2,$$

where h_1 and h_2 are the heights of the window head and the window sill respectively above the working plane. If x is the distance of the working point from the window plane, y its distance from the vertical plane bisecting the window at right angles, and r its distance from the vertical centre-line of the window, so that $r^2=x^2+y^2$, the formula is

$$\frac{xW(k_1-k_2)}{2\pi f} = (r^2+k_1)\,(r^2+k_2)-y^2W^2 \ldots\ldots(2)$$

8. The penetration can be calculated by taking r−x=y=0. A figure

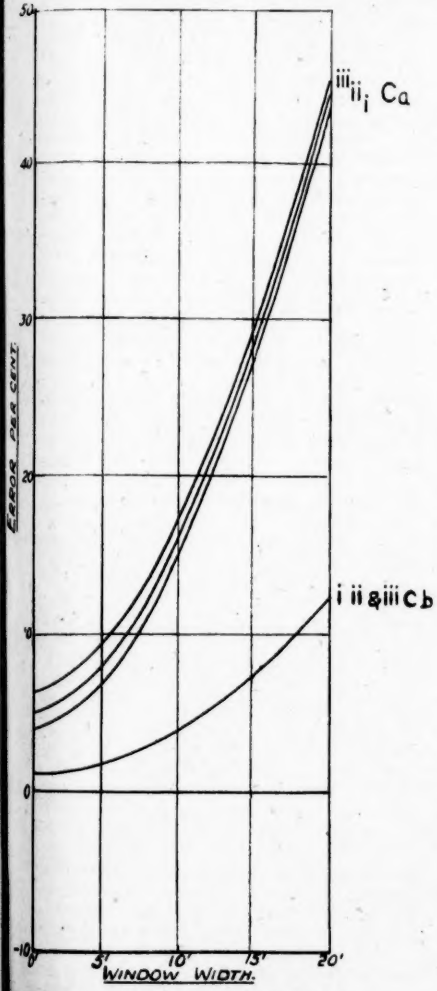

Fig. 5. Change in errors with C formula due to obstruction—i, no obstruction, ii, lower half, and iii, bottom three-quarters obstructed.

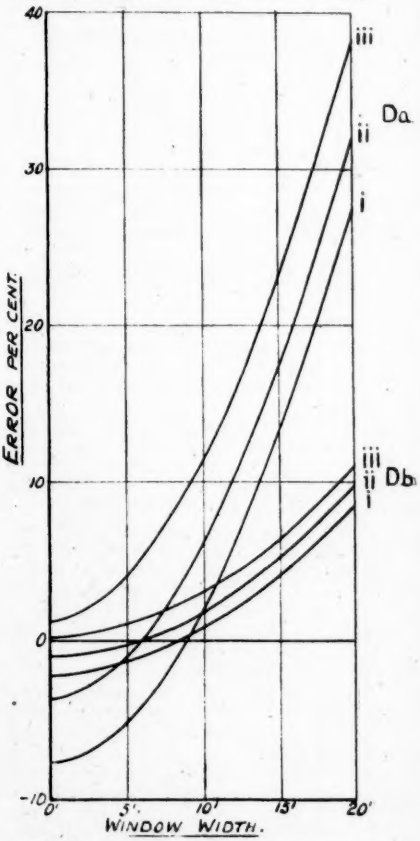

Fig. 6. Change in errors with D formula due to obstruction—i, no obstruction, ii, lower half, and iii, bottom three-quarters obstructed.

like Figs. 4, 5 and 6 would show that the errors due to the use of this formula are very small compared with those arising from formulae of the type of equation (1), but would not enable the faithfulness with which equation (2) represents the correct values to be appreciated. The comparison is therefore put in tabular form, the quantity recorded being the ratio of the daylight factor given by equation (2) to the correct value at a point 12 ft. from the window plane. The window dimensions are those given in paragraph 6.

Table of daylight factor ratios.

Window width ft.	No obstruction.	Lower half obstructed.	Bottom ¾ obstructed.
0	1.0000	1.0000	1.0000
1	1.0001	1.0000	1.0001
2.5	1.0001	1.0000	1.0000
5	0.9996	0.9996	0.9996
7.5	0.9980	0.9981	0.9982
10	0.9940	0.9943	0.9946
15	0 9743	0.9753	0.9765
20	0.9344	0.9367	0.9392

It will be noted that whether sky obstructions exist or not the errors only reach the range of experimentally measurable differences for windows of extreme width. At a point 24 ft. distant from the window the errors are very much less than those at 12 ft.: for instance, with an unobstructed window 20 ft. wide the ratio is 0.9934 in place of 0.9344.

9. To test the accuracy of the formula in different parts of the working plane the 5 per cent., 1 per cent., and 0.2 per cent. daylight factor contours have been calculated for a square window with its sill in the working plane. The curves are shown in Fig. 7, and for a few representative points of these contours numerical values obtained from calculations with the exact formula have been recorded in the figure. The errors due to the use of equation (2) are again all below the level of experimental determinations, and the whole available numerical evidence supports the view that we may confidently accept deductions from equation (2) as correct. Perhaps one almost trivial point should be mentioned. The curves plotted from this equation do not quite reach the plane of the window. The construction to be followed is to continue the curves from points where x is small to the points in which the vertical edges of the window meet the working plane. This part of the curve is, of course, of little or no practical interest.

10. The contours that have been calculated are for an unglazed window. Given a convenient means of computing these curves—and equation (2) is merely a quadratic in either x or r^2—it becomes a simple matter to derive other curves in which any desired allowances are made for changes of light intensity with differences in the direction the light takes from the window to the point of the working plane considered.

11. It remains to give the theoretical justification for the two formulae proposed. Consider then light entering the room through a small area of the window at Q and illuminating a small area of the working surface at P. The amount of light entering will be proportional to the area at Q, and that received at P will vary inversely as the square of the distance PQ. Because the area at Q is oblique to the direction of the light travelling to P, it is equivalent to the smaller area obtained by projecting the window area on a plane normal to PQ. Also the area of the working surface at P only receives as much light as the smaller area obtained by projecting normally to PQ. If we denote the area at Q, by a, the distance PQ by r, the height of Q above the working plane by h, and the distance of P from the plane of the window by x, these considerations indicate that the illumination at P due to the area at Q is proportional to

$$a \cdot \frac{1}{r^2} \cdot \frac{x}{r} \cdot \frac{h}{r} \text{ or } \frac{x}{r^4} \cdot ah$$

On this scale the illumination of a horizontal surface due to the whole sky is π, so that the daylight factor f for any unglazed window is found by summing the values of $\frac{x}{\pi r^4} ah$ for all the small areas a into which the whole area A of the window may be divided.

To carry out this summation there

is not the least need to invoke the meticulous technique of the integral calculus. Window areas are determined by considering the amount of daylight reaching parts of the room at a distance from the window. For such points the value of r changes very little as Q wanders over the window, and we shall get the right result by assigning to r some fixed value between the least and greatest distances. This makes $\frac{x}{\pi r^4}$ a constant, and we only have to sum ah. Now let each area be a rectangle of constant size, say one nth part of the area A. Then the sum ah is A/n times the sum of the n values of h alone, that is to say it is A multiplied by the average value of h for the whole window, or AH where H is the height of the centre of the window. We therefore obtain

$$f = \frac{xAH}{\pi r^4} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3)$$

where r is the mean value of the distance of the window from P.

Now in considering depth of penetration we can hardly make more than a trivial error whichever point of the window we use to determine r, but it is interesting to try to choose well. In the typical case the bottom of the window is substantially on the level of the working plane, so that x is the least possible value of r. If we made this choice our values of f would be slightly too high—an error in the undesirable direction. We should certainly not go to the opposite extreme and take the distances of the upper corners of the window. The middle of the window is on the near side, for it is obvious that more than half the window is further from P. We go too far in the opposite direction by taking the middle of the upper edge of the window. There do not seem any other convenient points to choose, so we consider dividing the r's, making some greater and the rest less than the mean. The best—and incidentally the most convenient—choice seems to be to make three of them equal to R, the distance of P from the top of the window, and the remaining one equal to the distance of P from the bottom of the window, that is, to x. This choice makes x/r^4 equal to $1/R^3$, so that

$$f = \frac{AH}{\pi R^3} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(4)$$

and

$$A = \frac{\pi f R^3}{H}$$

which is formula (1).

12. An exact expression for the calculation of daylight factors is easily constructed by integration, and is no doubt to be found in standard works on illumination. It is not, however, known that expressions have been developed which show explicitly how the chief factors enter the result and what magnitudes disturb the accuracy of the simplest formulae. The expression to be derived here is designed to remove this objection.

The point P of the working plane is identified as before by its coordinates (x, y, 0), and those of the point Q of the window are represented by (0, w. h). The element of window area at Q is therefore denoted by dh dw, and equation (3) shows that if $r^2 = x^2 + (y - w)^2 + h^2$ the contribution of this element to the daylight factor is $\frac{xh}{\pi r^4}$ dh dw:

accordingly

$$\frac{\pi f}{x} = \iint \frac{h}{r^4}\, dh\, dw,$$

where the integral extends over the whole area of the window. The indefinite integral is equal to

$$-\int \frac{dw}{2r^2} \text{ or } -\frac{1}{2(x^2+h^2)^{\frac{1}{2}}} \tan^{-1} \frac{w-y}{(x^2+h^2)^{\frac{1}{2}}}.$$

Now let N_1 and N_2 be the distances of P from planes normal to the window plane which pass through the vertical edges of the window, and D_1 and D_2 the distances of P from the lines which represent the top and bottom horizontal window edges. Then

$$\frac{2\pi f}{x} = \frac{1}{D_2}\left(\tan^{-1}\frac{N_1}{D_2} - \tan^{-1}\frac{N_2}{D_2}\right) - \frac{1}{D_1}\left(\tan^{-1}\frac{N_1}{D_1} - \tan^{-1}\frac{N_2}{D_1}\right) \ldots(5)$$

the usual theoretical expression. It will often be preferable to replace the

angle difference in each bracket by the single angle

$$\tan^{-1}\frac{WD}{D^2+N_1N_2}$$

where $W = N_1 - N_2 =$ the window width. The most instructive formula follows on carrying the process farther.

$$\begin{aligned}\frac{4\pi f}{x} &= \frac{2}{D_2}\left(\tan^{-1}\frac{N_1}{D_2}-\tan^{-1}\frac{N_2}{D_2}\right)\\ &\quad -\frac{2}{D_1}\left(\tan^{-1}\frac{N_1}{D_1}-\tan^{-1}\frac{N_2}{D_2}\right)\\ &=\left(\frac{1}{D_2}+\frac{1}{D_1}\right)\left(\tan^{-1}\frac{N_1}{D_2}-\tan^{-1}\frac{N_2}{D_2}\right.\\ &\quad \left.-\tan^{-1}\frac{N_1}{D_1}+\tan^{-1}\frac{N_2}{D_1}\right)\\ &\quad +\left(\frac{1}{D_2}-\frac{1}{D_1}\right)\left(\tan^{-1}\frac{N_1}{D_2}-\tan^{-1}\frac{N_2}{D_2}\right.\\ &\quad \left.+\tan^{-1}\frac{N_1}{D_1}-\tan^{-1}\frac{N_2}{D_1}\right)\\ &= \frac{D_1+D_2}{P}\tan^{-1}\frac{W(D_1-D_2)(P-Q)}{E+F}\\ &\quad +\frac{D_1-D_2}{P}\tan^{-1}\frac{W(D_1+D_2)(P+Q)}{E-F}\end{aligned}$$

.....(6)

where $P = D_1D_2$, $Q = N_1N_2 = y^2 - \frac{1}{4}W^2$,
$E = (D_1^2+Q)\,(D_2^2+Q)$, $F = PW^2$.

The small factors are $D_1 - D_2$ and W, so that the first angle is small, but the second may be large, in fact well outside the region in which the usual expansion is convergent. For example, the value of the tangent for one of the points marked in Fig. 7 is greater than 6.

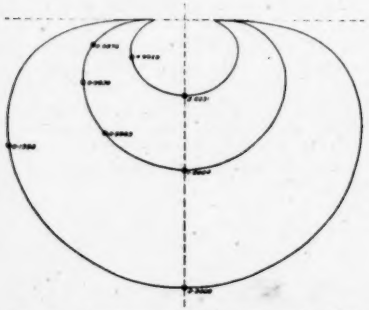

Fig. 7. Contours of 5%, 1% and 0.2% daylight factors for a square window with sill in working plane.

13. Under these circumstances it is useless to construct an approximate formula by taking a few terms of the expansion. In any event such a formula might prove too cumbersome for use. The procedure adopted was to infer from the argument of paragraph 11 that it should be possible to find a function ϕ (x, y) of the fourth order which would satisfy the relation

$$\frac{\pi f}{x}=\frac{AH}{\phi}=\frac{W(D_1^2-D_2^2)}{2\phi}=\frac{W(k_1-k_2)}{2\phi} \quad ...(7)$$

within small limits. The value of ϕ necessarily lies between the fourth powers of the distances of the nearest and farthest points of the window from P. It is to be expected that ϕ will involve the shape of the window. To determine ϕ the terms in the expansion of the two tangents of equation (6) were considered which could be made to fit an expanded form of equation (7). This led directly to formula (2), which has been found by numerical comparison to give such satisfactory results. Clearly such close agreement could not have been anticipated in advance.

14. The fact that close agreement has been found in a small number of special examples is not conclusive evidence that satisfactory agreement will always be obtained. The evidence required to establish this conclusion is of a different kind, and can be obtained by considering how closely daylight factors computed by equation (2) are additive when one window area is added to another. For narrow windows our formula certainly gives correct results for all values of h, and h_2. Factors given by the exact formula are additive without error whatever values W, h, and h_2 may have. Consider the factors given by equation (2). In the first place let the windows be of the same width and arranged vertically above one another. Let f_1, f_2, f_3 be the factors for windows with the values k_2, k_3; k_3, k_1; k_1, k_2. Cyclic order is

taken for mathematical simplicity. Then we have directly from the formula

$$\left(\frac{xW}{2\pi}\right)^2(k_1-k_2)(k_2-k_3)(k_3-k_1)\times\left(\frac{1}{f_1f_2}+\frac{1}{f_2f_3}+\frac{1}{f_3f_1}\right)$$

$$=\Sigma(k_2-k_3)\left\{(r^2+k_1)(r^2+k_2)-y^2W^2\right\}\times\left\{(r^2+k_3)(r^2+k_1)-y^2W^2\right\}$$

$$=-y^2W^2(k_1-k_2)(k_2-k_3)(k_3-k_1).$$

Translating this result into the more usual notation where only positive areas and factors are considered, we see that if two windows of the same width are superposed immediately above one another, and the daylight factors of the two parts are f and f′, the daylight factor F for the two areas together will, according to equation (2), be F where

$$F=f+f'+\left(\frac{2\pi y}{x}\right)^2Fff' \quad .....(8)$$

instead of F = f + f′, as the exact formula would give. Now the error term contains the product of three daylight factors, and each of these is small. It follows that the error is negligible. It is interesting to note that the width of the window does not appear in this result, and that errors are only likely to become appreciable near the plane of the window where y/x may become large. In this region it has already been noted that the formula is inapplicable, but that values here are also of no practical importance.

We now consider the addition of window areas side by side. It will be sufficient to consider the addition of two windows each of width W to make a combined window of width 2W. We will suppose k_1 and k_2 relate to the wide window, so that

$$k_1=h_1^2+\frac{1}{3}W^2 \quad , \quad k_2=h_2^2+\frac{1}{3}W^2.$$

For one of the parts, say that with the daylight factor f, the point with co-ordinates (x, y) relative to the wide window will have co - ordinates (x, y + ½W) relative to the part, so that the corresponding value of $r^2 + k$, is

$$x^2+(y+\tfrac{1}{2}W)^2+h_1^2+\frac{1}{12}W^2$$

or $$x^2+y^2+h_1^2+\frac{1}{3}W^2+yW,$$

i.e., $$r^2+k_1+yW.$$

For the other part the sign of W is changed. We therefore have equations which may be written

$$\frac{xWC}{\pi F}=R-4y^2W^2,$$

$$\frac{xWC}{2\pi f}=R-\tfrac{1}{4}W^2-yW\left\{(4R+C^2)^{\frac{1}{2}}-W^2\right\},$$

$$\frac{xWC}{2\pi f'}=R-\tfrac{1}{4}W^2+yW\left\{(4R+C^2)^{\frac{1}{2}}-W^2\right\}.$$

By constructing two expressions equal to R $(R-4y^2W^2)$ we obtain the relation

$$F=f+f'-\left(\frac{2\pi y}{x}\right)^2Fff'+\frac{2\pi y}{x}\cdot\frac{W^2}{h_1^2-h_2^2}F(f-f')-\left\{\frac{\pi W^3}{4x(h_1^2-h_2^2)}\right\}F(f+f').....(9)$$

The first of the three terms representing departures from strict additivity is equal in magnitude though opposite in sign to that when vertical combinations are made, and we have seen that this is negligible. The second term contains the small factor F and the much smaller term representing the difference in the factors for the two parts, and this also will be negligible. The last term contains three factors which tend to be small—they are substantially $\left(\frac{W}{x}\right)$ and F, the latter repeated. This term also tends to be small until the window becomes decidedly wide. It is the only term which affects the depth of penetration, and it has already been shown that the errors here are very small.

Taking now into account that we have shown that no error is made for any narrow window, that failures to add daylight factors produce very minor effects, and that these effects

by the time the square shape is reached are inappreciable, we may safely conclude that equation (2) is reliable for use in all practical cases. Unlike the formal solution in any of its possible shapes, equation (2) is well suited to numerical work.

15. In conclusion it should be noted that, in demonstrating that daylight factors add satisfactorily, we have justified their subtraction. That is to say we have shown that we shall obtain correct results if we use equation (2) when obstructions affect the amount of sky visible from any part of the working plane. Contours in these cases may either be computed directly by making h_2 proportional to x, or be constructed from sets of contours for windows which all come down to a standard level, let us say windows with their sills in the working plane. We are free to take whichever course happens to be the more convenient.

Papers Read Before Centres and Groups

A PRIMER ON LIGHTING SCHEMES. By J. B. SAUNDERS.

Summary of a paper read before the Nottingham Centre (Midland Area) on April 30, 1943.

In the initial part of his paper the author briefly explained fundamental principles and terms used in illuminating engineering, and commented upon the use of photometric apparatus. Subsequently methods of measuring the flux of light yielded by a source in the terms of lumens, the construction of polar curves, and the Rousseau diagram were discussed. The author then turned to the consideration of the comparative effects of different forms of reflecting surfaces and proceeded to design a reflector for a specific purpose in accordance with the method developed by Jolley, Waldram, and Wilson. The influence of variation in certain constants on the output of this reflector was studied. Subsequently the familiar formula enabling the total flux of light to be computed from the illumination, the area illuminated, the depreciation factor, and the coefficient of utilisation was analysed. In conclusion, the importance of securing a low voltage drop and good power factor in lighting installations was emphasised and methods of calculating loss of light involved were examined.

Additions to List of Members.

The following applicants have been duly elected by the Council to membership in the Society, and their names have been added to the list of members:—

CORPORATE MEMBERS:—

Byrne, E. J.....5, Sunningdale Avenue, Whitefield, LANCS.
Cantrill, F. A. ..... 60, Village Street, DERBY.
Gilman, V. A.....90, Chaddesden Lane, DERBY.
Gleadhall, G.....44, Stradbroke Road, Richmond, SHEFFIELD, 9.
Haw, J.....1, Clifton Villas, BRADFORD.
Pring, W.....23, St. Francis Road, Whitchurch, CARDIFF.
Sadler, M. R. H..... Mayfield Cottage, Ashbourne, DERBY.
Shannon, H. B.....71a, Queen Street, Newton Abbot, DEVON.
Sheppard, A. G. .... 31, Hannam Court, Charles Street, LEICESTER.

THE ANNUAL GENERAL MEETING

The annual meeting of the Illuminating Engineering Society took place in the Lecture Theatre in the Institution of Mechanical Engineers, at 4.30 p.m., on Tuesday, May 11, 1943, when the President (Mr. R. O. Ackerley) was in the chair.

The Hon. Secretary having read the notice convening the meeting, it was agreed that the minutes of the last meeting, which had been published in THE TRANSACTIONS, should be taken as read.

The President then proceeded to present the Report of the Council and statement of accounts for the year 1942. He explained that the present Report was in the nature of a transition one. This was the first occasion on which the Report had covered the complete previous year, thus dealing with the same period as the statement of accounts

Election of Officers and Members of Council

As a result of the change the Report did not deal with the Election of Officers and Members of Council in the present year. The President reported that no other nominations having been received, the Council's nomination for Officers were automatically elected as follows:—

President—Dr. H. Buckley.

Vice-Presidents—Mr. E. Stroud, Dr. W. M. Hampton, and Mr. H. C. Weston.

Hon. Treasurer—Mr. N. V. Everton.

Hon. Secretary—Mr. J. S. Dow.

Continuing, the President said that it gave him very great pleasure to call attention to the fact that Mr. Dow had been elected an Honorary Member of the Society.

In regard to Members of Council a ballot had been conducted. The President then opened the report from the scrutineers, and reported that the following had been elected: Mr. H. E. Chasteney, Mr. W. E. J. Drake, Mr. F. S. Ette, Mr. J. G. Holmes, Mr. W. C. Huston, Mr. H. Lingard, Mr. J. F. Stanley, Dr. J. W. Whitaker, Mr. T. Wilkie.

The President expressed the thanks of the Society to the two scrutineers (Mr. M. W. Peirce and Mr. C. Strange) for their services.

Some Recent Developments

The President then proceeded to summarise some of the salient features of the Report of the Council, drawing attention to the continued progress being made by the various Centres and Groups and the substantial increase in membership, which now totals over 2,000. Developments since the end of 1942 had included the decision of the Bath and Bristol Groups to unite and constitute themselves a Centre in the Western Area and the receipt of an application to form a new Group in Derby. The President also referred to the fact that several members of the Society were serving on the Committee of the Department for Scientific and Industrial Research, which was concerned with the lighting of post-war buildings, and stated that on several occasions the Society had given evidence before this Committee. The financial position of the Society was now somewhat better than in previous years, but in the future further expenditure would be necessary in connection with the organising and administrative side of the Society and additional revenue would be required. Allusion was made to the interest evinced by members in the future post-war activities and development of the Society, and to the letter on this subject which he had addressed to all members of the Society, whose views would be welcomed.

In conclusion, the President referred to the retirement of Mrs. A. W.

Beuttell (Miss J. E. Moreton), who had been associated with the Society for more than thirty years, and to whom all members extended their best wishes for her future. He also paid a tribute to Miss Wright, who had been ill but was now back at work.

Adoption of Report and Accounts

The following resolution was then put to the meeting by Mr. W. R. Rawlings and seconded by Mr. A. E. Iliffe, both of whom expressed appreciation of the evidence of prosperity contained in the Report:—

> That the Report of the Council and the accounts of the Illuminating Engineering Society for the period January 1, 1942, to December 31, 1942, be hereby adopted, and that a vote of thanks be extended to the President, Council, and officers for their efforts on behalf of the Society during the past session.

On being put to the meeting the Report was declared carried unanimously.

It was then proposed by Mr. Hime and seconded by Mr. C. R. Winstone:—

> That the meeting records the appreciation of the services of Messrs. Robert J. Ward and Co. as auditors of the Society and approves their re-election for the next session.

This resolution, too, was declared carried unanimously. This terminated the formal business.

Address on "Light and Vision"

Following the annual general meeting a sessional meeting took place. After the minutes of the last meeting had been taken as read the President called upon Sir John Herbert Parsons to deliver an address on "Light and Vision." He recalled that Sir John was one of the few original members of the Society and one of its pioneers. He was responsible for the very first paper read before the Society (in 1910), following the inaugural address of the late Professor Silvanus P. Thompson, when he took for his subject "Glare: Its Causes and Effects." Sir John was also the only original member of the Departmental Committee on Lighting in Factories who was serving on the present committee—of which Sir Duncan Wilson, who acted as one of the secretaries of the original Committee, was chairman.

Sir John then delivered his address (see pp. 99-109), which consisted of a masterly review of problems associated with light and vision and their influence on the work with which the Society was concerned. Cordial appreciation of the address and references to the very valuable work which Sir John had done for the Society were expressed in the remarks of Sir Duncan Wilson and Dr. W. D. Wright, who respectively proposed and seconded a vote of thanks to the author. This vote was carried with acclamation and was briefly acknowledged by Sir John, after which members dispersed.

Informal Social Evening

At the subsequent informal social evening which had been arranged by the President, by kind invitation of the General Electric Company, Ltd., at Magnet House (Kingsway, London) about 250 members and friends were present. They were welcomed by Dr. A. H. Railing, chairman and joint managing director of the General Electric Company, Ltd., who referred in appreciative terms to the work of the Society. A humorous and musical programme, prepared by the President and other members of the Society and friends, was then given and very much enjoyed by all present.

In conclusion, a vote of thanks to the General Electric Company for their hospitality, and to the President and others who had taken part in this entertaining programme, was proposed by Mr. F. C. Smith and was carried with acclamation.